A Dominating Sets and Target Radius Based Localized Activity Scheduling and Minimum Energy Broadcast Protocol for Ad Hoc and Sensor Networks

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***Abstract*— Several localized broadcasting protocols for ad hoc and sensor networks were proposed recently, with the goal of minimizing the energy consumption, while still guaranteeing a total coverage of the network. Also, several activity scheduling protocols were proposed, which select nodes in a connected dominating set to be active, with the rest of nodes left in sleep mode for energy savings. This article is the first to consider both problems as a single combined one, in which a localized protocol is proposed as a solution. First, each node considers only neighbors whose distance is no greater than the target radius (which depends on the power consumption model used), and neighbors in a localized connected topological structure such as *RNG* or *LMST*. Then, a connected dominating set is constructed using this subgraph. Next, nodes not selected for the set are sent to sleep mode (they periodically wake up for sending and receiving messages from associated closest dominating set nodes). Nodes in selected dominating set remain active and apply neighbor elimination based broadcasting (reduced to a subset of dominant neighbors with the help of the *RNG* or *LMST*), with transmission range adjusted to their furthest neighbor (in the considered subgraph) not covered by other transmissions. The algorithm has been implemented and compared with a centralized (*BIP*) and target radius based minimum energy broadcasting (*TR-LBOP*) protocol (which do not place any node to sleep mode). It is shown that our algorithm requires similar amount of energy for broadcasting as *TR-LBOP*, but in addition also has energy savings coming from sleep mode status of significant number of nodes. Moreover, our protocol offers the advantage of a smaller latency, since fewer nodes participate in the broadcast.**

I. Introduction

Ad hoc networks are formed by autonomous devices, which communicate by using radio interfaces. As ranges are limited, direct communications can only occur between mobiles that are sufficiently near each other. Data communication tasks are therefore performed in a multi-hopping fashion, by relaying messages at intermediate nodes. Examples include conference, rescue, battlefield scenarios, mesh networks for wireless Internet access, and sensor networks for monitoring environment and reporting data to a base station.

In a broadcasting task, a message is to be sent from one node to all the other ones in the network. It is a frequently required operation needed for route discovery, information dissemination, publishing services, data gathering, task distribution, alarming, time synchronization, and other operations. If we consider hardware capable of radius adjustment, developing an efficient broadcast protocol becomes a very interesting challenge. Due to the limited ranges of communication, many nodes will have to participate in the task, and finding which combination of retransmitting nodes and radii length will lead to an optimal energy consumption is known to be an NP-complete problem [1] even as a centralized problem. In ad hoc and sensor networks, the problem is even more challenging since global network knowledge, needed to simulate a centralized solution, requires extremely high communication overhead for maintenance when nodes move or change activity status. This communication overhead requires energy that defeats the savings made in the centralized solutions (and many of them were proposed in literature very recently). It is therefore desirable to consider only localized protocols. In a localized protocol, each node makes the decision about the necessary delay and transmission radius for retransmitting based solely on the knowledge of its direct neighbors (one-hop knowledge), or, in some cases, its two-hop neighbors (neighbors of neighbors).

As energy consumption obviously depends on the transmission radius, an efficient way to minimize it is to use radii as small as possible. This observation was explored in all proposed protocols. However, a commonly accepted energy model adds a constant to the consumption, regardless of the chosen radius, to take into account miscellaneous costs (such as minimal power needed for correct message reception). Considering this, minimizing the energy consumption at each node may not be the optimal behavior, because small radii require more nodes to participate in the broadcasting process. This may lead to increased global energy consumption, although each node has tried to minimize its own consumption.

The idea of applying an optimal target radius, whose length balances the energy consumption at each node and the number of needed retransmitting nodes, has been recently introduced in [2]. This concept was used to alter the behavior of nodes in a protocol named *LBOP* (*LMST based broadcast oriented protocol*) [3]. When a retransmission is needed, each node sets its radius to reach its furthest *LMST* neighbor which did not receive previous messages. The modified version, named *TR-LBOP* (for *Target Radius LBOP*), was shown to improve the performances of the original protocol, proving the existence of an optimal radius. The protocol *TR-LBOP* was also shown experimentally to be competitive with a globalized protocol.

In this paper, we propose to use the concept of optimal target radius in a new kind of broadcasting protocol. After a first step of topology control, whose goal is to bring radii as near as possible to a target radius, a connected dominating set is computed. The latter is used to determine which nodes will relay the broadcast message, and which ones will be passive. This protocol offers the following advantages over *TR-LBOP*:

- A lower latency. Indeed, nodes in *TR-LBOP* wait for a given duration before retransmitting, thus greatly increasing the total duration of the broadcast.
- Non-dominant nodes can adopt sleep mode. Indeed, only dominant nodes have to relay the message, while passive ones do not participate in the broadcast. This provides additional important energy savings, of even greater magnitude than the energy savings coming from adjusting transmission radii for ongoing broadcast traffic.

It was experimentally confirmed in [4] that the difference in energy consumption between an idle node and a transmitting node is not major, while a major difference exists between idle and sleep states of nodes. Therefore the most energy efficient methods will select static dominating set for a given round, turning all remaining nodes to a sleep state. This observation confirms the benefits for using our approach.

The rest of this paper is organized as follows. In the next section, we give the needed preliminaries on network model. In Sec. III, we give a literature review of existing energy-efficient protocols for ad hoc networks. We present in Sec. IV our protocol and then we give in Sec. V the experimental results obtained. Finally, we give a brief conclusion and some perspectives for future works.

II. Preliminaries

We represent a wireless network by a graph $G = (V, E)$, V being the set of vertices (the nodes) and $E \subseteq V^2$ the set of edges which represent the available communications: if a node v is a physical neighbor of a node u (v receives the messages emitted by u), then there exists $(u, v) \in E$. If we assume that all nodes have the same communication radius, denoted by R, then the set E is defined by:

$$E = \{(u, v) \in V^2 \,|\, d(u, v) \leq R\}.$$

$d(u, v)$ being the Euclidean distance between nodes u and v. Each node u must be assigned a unique *identifier* (*id*). We define the neighborhood set $N(u)$ of a node u as:

$$N(u) = \{v \,|\, (u, v) \in E\}.$$

We refer to the size of this set, $|N(u)|$, as being the degree of u. The density of the graph is then defined to be the average degree of each node. We measure the distance between two nodes u and v in terms of number of hops, which is simply the minimum number of links a message has to cross from u to v.

We assume that each node (regularly or based on its mobility) emits special short messages, named *HELLO* messages, and maintains an internal neighborhood table. Simply, each time a node u receives from a node v an

HELLO message, u adds v to its neighborhood table, or updates the entry if v was already there. Too old entries are regularly removed from the table, as corresponding nodes have not signaled themselves recently.

If the distances between neighbors are needed, the easiest method to obtain them is to have nodes add their position in their *HELLO* messages. Positions can be acquired by using a location system like the *GPS* (*Global Positioning System*). Other methods can be used, like deducing distances to neighbors by measuring the reception power of messages and including them in *HELLO* messages.

By using radio interfaces, the energy consumption of an emission obviously depends on the transmitting range r. The higher r is, the higher the consumption will be. In the real world, there exists a constant to be added to this consumption in order to take into account an overhead due to miscellaneous things, such as signal processing. The general energy formula is so:

$$E(u) = \begin{cases} r(u)^\alpha + c & \text{if } r(u) \neq 0, \\ 0 & \text{otherwise.} \end{cases}$$

The values of α and c depend on the environment and hardware. One common accepted model, used in this article, is given by Rodoplu and Meng [5] as $E(u) = r(u)^4 + 10^8$.

III. Related work

The most basic solution to broadcast a message, known as the *blind flooding*, is to have each node relay it once: if the network is connected, a total coverage is ensured. Unfortunately, this protocol leads to a lot of duplicated packets and thus to a huge energy consumption. Many solutions have been proposed to replace this inefficient solution, and mainly two families can be distinguished. The goal of the first one is to reduce the number of needed emissions to obtain a total coverage, while the second one considers radius adjustment with suitable hardware to further reduce the energy consumption.

A remarkable protocol that belongs to the first family is named *MPR* (*Multipoint Relay Protocol*) and has been proposed by Qayyum et al. [6]. It is a greedy heuristics which makes nodes select their own relays before retransmitting. This selection, which is forwarded with the broadcast packet, is composed of an optimal subset of physical neighbors that entirely covers the two-hops neighborhood. Nodes that receive this packet but do not have been selected simply drop it. This protocol is used in an *IETF* standardized routing protocol named *OLSR* (*Optimized Link State Routing*) [7].

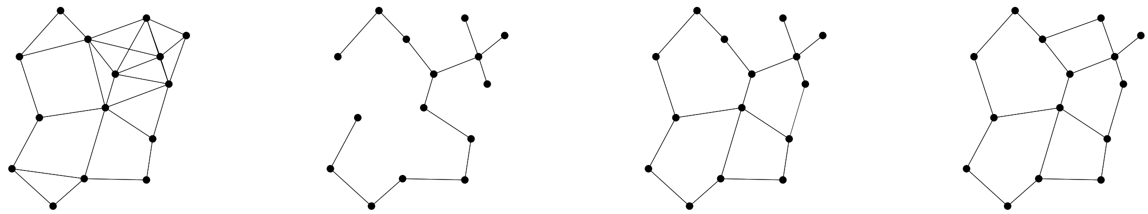
The *NES* (*Neighbor Elimination Scheme*) was independently proposed in [8] and [9]. In this scheme, nodes do not relay the message immediately but monitor their physical neighborhood for a given time. Each neighbor that receives a copy of the same message is eliminated from an internal uncovered neighbors list. If this list becomes empty before the timeout occurs, the retransmission is canceled. This method has been further improved by other protocols like *RRS* (*RNG Relay Subset*) [10], which reduces the set of monitored neighbors (and thus the probability of retransmission) by using a special graph named *RNG* (*Relative Neighborhood Graph*) [11]. The neighbor elimination protocol will be applied as part of our solution.

Some broadcasting protocols are based on the concept of connected dominating sets. A connected dominating set is a subset of nodes, written V_{dom}, which satisfies two properties:

- all nodes in the graph must be either in V_{dom} or directly connected to a node in V_{dom}. This subset is then called a dominating set,
- it has to be connected.

Finding the smallest possible connected dominating set is a NP-hard problem and requires a global knowledge of the network. However, some localized algorithms to compute an efficient sub-optimal set have been proposed and can thus be used in ad hoc networks. Amongst them is the *Generalized Self-Pruning Rule* proposed by Dai et al. [12]. This algorithm computes an efficient connected dominating set by using solely the knowledge of the physical neighborhood, without exchanging any messages to decide which nodes are in the connected dominating set (the variant of this protocol having such property is described in [13]). The Generalized Self-Pruning Rule algorithm can be described as follows. First, each node checks if it is intermediate, that is, whether it has at least two neighbors not directly connected. Then each intermediate node A constructs a subgraph G of its neighbors with higher ids. If G is empty or disconnected then A is in the dominating set. If G is connected but there exists a neighbor of A which is not neighbor of any node from G then A is in the dominating set. Otherwise A is covered and is not in the dominating set. Non-intermediate nodes are never dominant. To broadcast a message, dominant nodes are the only needed relays to reach the whole network.

Many protocols that belong to the second family (ad-



(a) Unit graph (b) MST (c) LMST (d) RNG

Fig. 1
EXAMPLE OF A UNIT GRAPH AND ITS ASSOCIATED SUBGRAPHS.

justed transmission radii) are based on the computation of a connected subgraph of the original network graph. Most of them use one of the following three subgraphs:

- the *MST* (*Minimum Spanning Tree*),
- the *RNG* (*Relative Neighborhood Graph*), which removes the longest edge of any triangle in the graph and has an average degree of 2.6. This graph was introduced by Toussaint [11],
- the *LMST* (*Local Minimum Spanning Tree*), in which nodes compute the *MST* of their physical neighborhood and choose a radius that covers only neighbors in this subgraph. This graph was proposed recently by Li et al. [14]. It has an average degree of 2.04 and is a subgraph of the *RNG* [3].

Figure 1 illustrates these subgraphs. It can be noticed that only the *MST* has a centralized computation: the knowledge of the whole topology of the network is required for its computation. The *RNG* and the *LMST* can be computed by localized protocols (moreover, the protocols do not require any message exchange).

Wieselthier et al. defined in [15] a topology control algorithm which is based on the *MST*. Each node chooses a radius that covers only neighbors in the *MST*. Since, by its construction, this graph is connected, the new graph derived from this range assignment is also always connected. The omni directional one-to-all nature of transmission allows to cover two or more *MST* neighbors of a node with a single transmission. Some transmissions can be omitted by applying neighbor elimination principle. This method offers good results, but is costly for implementation in ad hoc networks because of its centralized computation. Other protocols that use locally defined graphs instead of *MST* have since been proposed: the protocol *RBOP* (*RNG Broadcast Oriented Protocol*) [16] uses the *RNG* while *LBOP* (*LMST Broadcast Oriented Protocol*) [3] uses the *LMST*.

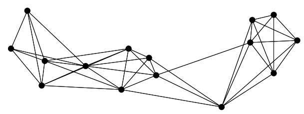
In the same paper, Wieselthier et al. also defined a centralized protocol named *BIP* (*Broadcast Incremental Power*). This heuristics constructs a broadcast tree from a source node. Nodes are added one at time to the tree by choosing the less expensive action: either a node that is already emitting increases its radius or a node that is not emitting starts a new transmission. The ‘price’ of an action is the additional power needed to cover one more node. This protocol works well with any energy model and often makes optimal decisions.

Recently, a localized protocol named *TR-LBOP* (*Target Radius LMST Broadcast Oriented Protocol*) has been proposed [2]. While most of the other protocols try to reduce as much as possible the transmitting radius at each node, *TR-LBOP* considers the general energy model (in which a constant c has to be added for each transmission) and uses an optimal radius, theoretically derived, and experimentally confirmed. This radius is not too large (otherwise α causes large energy consumption), and not too small (otherwise c increases energy due to a high number of retransmitting nodes). The value of this optimal radius is theoretically obtained by using an hexagonal tiling of the network area. For an energy model with $\alpha > 2$ and $c \neq 0$, the optimal radius r is:

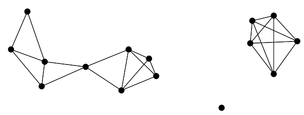
$$r = \sqrt[\alpha]{\frac{2c}{\alpha - 2}}.$$

This value may be increased independently by each node if required, to preserve the connectivity (that is, a localized connected structure is also applied). The protocol *TR-LBOP* is found to have energy savings comparable to *BIP*.

Wu and Wu [17] applied connected dominating sets for adjusting transmission radii in deriving a localized



(a) $R_t = 100$ meters



(b) $R_t = 65$ meters

Fig. 2
LOSS OF CONNECTIVITY WITH AN ADJUSTED RADIUS.

minimum energy broadcasting protocol. Each node applies its distance to the farthest neighbor as its *id* in dominating set definitions, so that node with smaller such maximal distance is favored in dominating sets. Each non-dominating set node is associated with only one dominating node set, to further reduce transmission radii. Neighbor elimination is also applied to further reduce the radii for particular broadcasting task. This protocol has some similarity with the one described here, but misses one of the key requirements in dense networks, to apply target radius, to achieve reasonable results compared to centralized solutions.

In the next section, we describe our localized protocol that incorporates target radius with other mentioned concepts in an optimal way.

IV. TARGET RADIUS AND DOMINATING SETS BASED BROADCAST PROTOCOL

The main idea of our new protocol is to impose to nodes a transmission range which should be as near as possible to the optimal radius, as described in the previous section. However, restraining radii in a localized manner is not sufficient, as connectivity must be maintained. Figure 2 shows this problem with two different target radii (R_t). If nodes choose 100 meters as a target radius, the resulting network is connected, while it is not the case with R_t=65m. This clearly illustrates the need for some nodes to use a longer radius to preserve the connectivity. To do this, we chose to use locally defined graphs, like the *RNG* or the *LMST*.

Our method assumes that there exists an optimal radius, which we use here as a target radius R_t ($0 < R_t \leq R$). Given this radius, our protocol is divided into two steps:

1) Adapt the topology of the network so that each node chooses a radius as close as possible to R_t, while still maintaining the connectivity.
2) Select dominant nodes to relay the message.

Topology control using R_t

Let $G = (V, E)$ be a connected graph and R_t a given target radius. To preserve the network connectivity while modifying the transmission range of nodes, we compute a subgraph $G' = (V, E')$, which has to be connected, bidirectional and computed locally. Some good examples of such graphs are the *RNG* or the *LMST*.

From G, G' and R_t, we compute a range assignment r defined by:

$$\forall u \in V,\; r(u) = \max\{d(u,v) \mid \quad d(u,v) \leq R_t \\ \qquad\qquad\qquad\qquad\qquad\qquad \vee (u,v) \in E'\},$$

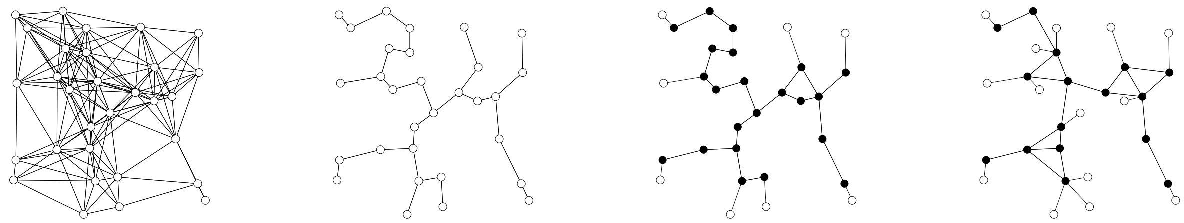
$d(u, v)$ being the Euclidean distance between nodes u and v.

In other words, each node chooses a range that covers all its neighbors closer than R_t, and all its neighbors in the graph G'. The topology we keep is the symmetrical part of $G_r = (V, E_r)$, the graph induced by r: unidirectional links are simply removed. An asymmetrical graph could cause problems when computing a dominating set over it. We denote this graph by $G_{R_t} = (V, E_{R_t})$, with $E_{R_t} = E_r \cap E_r^{-1}$. This new graph is obviously connected, since it contains G'. After this step, every node has a radius as close as possible to R_t with a connectivity preserved, as long as the original graph was connected.

Energy-efficient Dominating Sets

Given an original graph G, a connected subgraph G' and a target radius, we have obtained a connected graph G_{R_t}. To perform the broadcast over this new graph, we use a connected dominating set scheme. To compute such a set, many algorithms have been proposed [18], [12], [19], and any of them can be used.

Hence, the set of vertices is now composed of two parts: the first one, D, composed of the dominant nodes and the second one, $\overline{D} = V \setminus D$, composed of all the non-dominant nodes. Each non-dominant node u of $\overline{D}$ is associated with a dominant neighbor which is the closest one to u. This dominant node, denoted by $p(u)$ is in charge of u, meaning it has to choose a



(a) Unit Graph (b) LMST (c) $R_t = 50$ (d) $R_t = 150$

Fig. 3

UNIT GRAPH WITH ITS LMST ($R = 250$) AND DOMINATING SETS AFTER TOPOLOGY CONTROL WITH $R_t = 50$ AND $R_t = 150$.

radius that can cover u when this one is not covered by a transmission which reaches $p(u)$. This coverage is needed if u is awake, otherwise (if u is sleeping), the distance to u does not need to be considered in broadcasting process. Note that, on our experiments, we assumed the need for coverage despite possible sleep status, since no significant differences were discovered.

For instance, Fig. 3 shows a unit graph ($R = 250$) with its associated (symmetrical) *LMST*. We have applied our topology control algorithm for two different values of R_t. For both cases, we have computed a dominating set by using the generalized rule [12]. Black nodes are dominant, while white ones are non-dominant. Some edges have been removed for simplicity reasons: non-dominant nodes are only linked to their closest dominant node.

Let u be a node of V. We denote by $N_D(u)$ the set of dominant neighbors of u in G_{R_t}. If u belongs to D, we denote by $N_{\overline{D}}(u)$ the set of non-dominant neighbor nodes (in G_{R_t} graph) associated with u ($p(v) = u$). The broadcast algorithm then proceeds as follows:

1) A dominant node u that wishes to launch a broadcast emits its message with the range which covers $N_D(u)$ and $N_{\overline{D}}(u)$.
2) A non-dominant node that wishes to launch a broadcast emits its message to its nearest dominant neighbor.
3) A dominant node u that receives the message rebroadcasts it with the range which allows to cover non-covered nodes in $N_D(u)$ and $N_{\overline{D}}(u)$. It does not take into account neighbors that have been covered when it received the message.
4) A non-dominant node that receives the message never relays it.

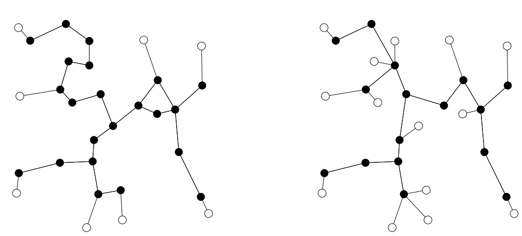
We further reduce the complexity of the dominant subgraph by computing the *RNG* of it. By using this graph, every dominant node has just to cover his dominant neighbors that belongs to the *RNG*, which can furthermore reduce the needed radius in the process of broadcasting. For instance, Fig. 4 gives the final graphs where we have computed *RNG* over dominant node subgraph of Fig. 3. Note that one can also use *LMST* instead of *RNG* for the same purpose.

V. PERFORMANCES

In this section, we give experimental data for our proposed protocol *TRDS*. We compare it with two other ones:

- *TR-LBOP*, because it is the first proposed protocol that uses the idea of an optimal radius.
- *BIP*, which is one of the best centralized solutions.

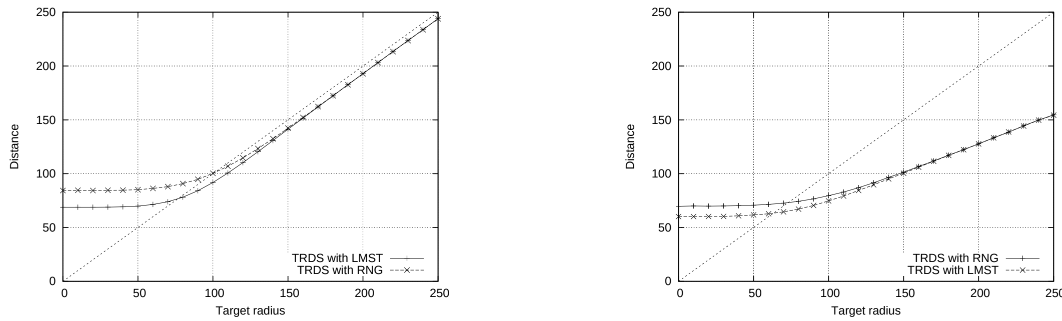
As an energy model, we used common parameters given by Rodoplu and Meng [5], so that the energy consumption of an emission with a radius r is given by:



(a) $R_t = 50$ (b) $R_t = 150$

Fig. 4

FINAL GRAPHS WITH DOMINATING SETS AND ASSOCIATED NON-DOMINANT NODES.

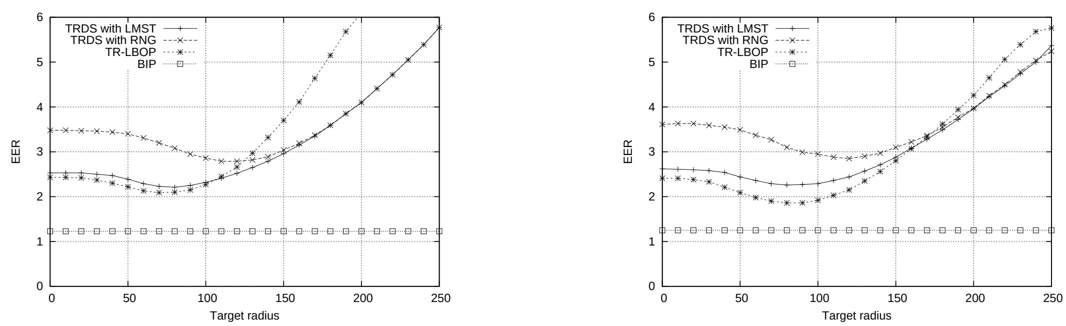


(a) Radii assigned to nodes

(b) Distance between dominant neighbors

Fig. 5

EFFICIENCY OF THE TOPOLOGY CONTROL STEP.



(a) Uniform distribution

(b) Non-uniform distribution

Fig. 6

EER FOR VARYING R_t (DENSITY 50).

$$\mathrm{PC}(r) = r^4 + 10^8.$$

In our simulations, the network is static and is always composed of 300 nodes randomly placed in a square area which size is computed to obtain a given density. The *MAC* layer is assumed to be ideal, that is, no collision occurs when two physical neighbors emit at the same time. The initial maximum communication radius R is fixed to 250 meters. The timeout for the neighbor elimination scheme in *TR-LBOP* is randomly generated. For each measure, 250 broadcasts are launched and for each broadcast, a new connected network is generated.

To compare the efficiency of the different protocols, we compute a ratio that we call *EER* (*Expanded Energy Ratio*), which represents the energy consumption of the considered protocol compared to the energy that would have been spent by a simple blind flooding. The value of *EER* is so defined by:

$$\mathrm{EER} = \frac{E_{\mathrm{protocol}}}{E_{\mathrm{flooding}}} \times 100.$$

To illustrate the existence of an optimal radius, we compare protocols by varying the target radius between 0 and the maximum range (which is set to 250 meters). Each time, the protocol *TRDS* is used in conjunction either with the *LMST* or with the *RNG* for the topology control step.

We used a uniform distribution of nodes in the network area for all the figures that do not have any indication about it. To achieve a non-uniform distribution, we divided the area into 9 squares, in which a different number of nodes were placed. This is illustrated by Fig. 7, where X is simply equal to the total number of nodes divided by 21. Thus the total number of nodes is correct, while some area are more dense than others.

We first illustrate the effectiveness of the topology control step with Fig. 5. Subfigure (a) gives the average radius assigned to the nodes after the first step of our protocol, and shows that the target radius parameter greatly influences the chosen radii. By changing its value, we are able to control these radii, except for too low values, where nodes must use a longer one to keep the connectivity. The radius needed to keep this connectivity is obtained thanks to the subgraph G'. As only dominant nodes relay the broadcast message, with a radius that allows them to cover their dominant neighbors, the average distance between dominant neighboring nodes mostly determine the final energy consumption. We thus give in (b) this average value, and once again it can be observed that the distance between dominant neighbors can be controlled. So, as demonstrated by this figure, our topology control works as intended since we are able to adapt the topology by modifying the target radius.

In Fig. 6, we give the *EER* obtained by the various tested protocols for the density of 50. Subfigure (a) has been obtained by considering a uniform distribution of nodes in the area, while case (b) uses a non-uniform distribution of nodes. Firstly, it can be noticed that there exists a minimum energy consumption in our protocol *TRDS*, as in *TR-LBOP*, which proves that our protocol correctly takes into account the given target radius. Considering a value of 80 for the target radius, *TRDS+LMST* only consumes 2.21% of the energy that would have been spent by a blind flooding. Not surprisingly, the protocol *BIP* obtains the best results as it is centralized, but *TRDS* and *TR-LBOP* both obtain good results, considering they are localized. The difference of energy savings between *TR-LBOP* and the version of our protocol that uses the *LMST* for the topology control step is very small. If

3X	4X	X
4X	X	2X
X	2X	3X

Fig. 7

NON-UNIFORM DISTRIBUTION IN THE NETWORK AREA.

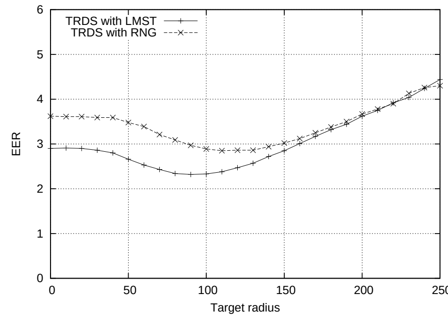


Fig. 8

EER WHEN USING *MPR-DS* (DENSITY 50).

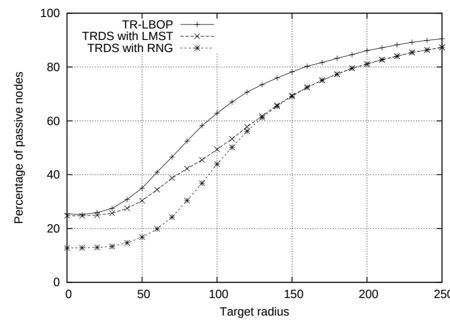


Fig. 9

PASSIVE NODES FOR VARYING R_t (DENSITY 50).

we consider that non-dominant nodes can enter a sleep mode, *TRDS* can offers better results, as these savings are not taken into account here. It can also be observed that all the considered algorithms work well regardless of the distribution, as cases (a) and (b) present very similar results. In our experiments, *TR-LBOP* seems to give better results with non-uniform distribution (1.86% against 2.09%).

Figure 8 gives the *EER* obtained when considering another algorithm to compute the dominating set. We used here the algorithm based on *MPR*, defined in [18]. It can be observed that performances are very similar to those presented in Fig. 6 (a). However, the generalized self-pruning rule gives slightly better results: the best *EER* obtained here by *TRDS* with *LMST* is 2.32% against 2.21% in Fig. 6 (a).

Figure 9 gives the average percentage of passive nodes for both localized protocols. In *TR-LBOP*, passive nodes are idle (nodes that receive the message but do not relay it) while in *TRDS* they are sleeping (non dominant nodes). If we consider a value of 80 for the target radius, which is the one that gives the best energy savings for both protocols, we can observe that *TR-LBOP* has a higher number of idle nodes than *TRDS* has sleeping nodes (52% against 42%). However, sleeping nodes consume far less energy than idle ones. Indeed, we assign energy values for the different states derived from [4]: sleeping nodes consume 1 unit of energy, idle nodes 15 units and transmitting nodes 28 units. As assigned radii are approximately the same for both two protocols, we can assume that a node consumes the same energy for a transmission, regardless of the protocol. For the target radius of 80 and 300 nodes, we obtain a consumption of 4998 units for *TRDS* and 6372 units for *TR-LBOP*. This illustrates the superiority of having sleeping nodes instead of idle ones.

VI. Conclusion

In this paper, we have presented a new broadcast protocol that relies on the computing of a connected dominating set to determine which nodes should relay the broadcast. As it is based on the concept of the existence of an optimal radius that minimizes the energy consumption, a topology control is firstly applied. This step can use any connected subgraph that can be computed locally. Results show that this protocol effectively present an optimal radius for which the consumption is minimal. Our protocol and *TR-LBOP* are both efficient, as their respective results are really near from each other. Our protocol takes the advantage if we consider that *TR-LBOP* has a higher latency due to the neighbor elimination scheme, and that further energy savings are obtained by putting non-dominant nodes into sleep mode.

As future works, we want to consider another kind of energy model, that introduces a consumption when mobiles receive a message. Indeed, some energy is spent for miscellaneous tasks upon reception (signal processing, *MAC* control messages), and this should be introduced into the computation of energy savings.

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